Space weather applications of the Spire nanosatellite constellation

Matthew Angling

1325 to 1335, 22 April 2021

Space Weather Workshop

Spire Earth Obs
Agile and operational

- We design, build, launch, and operate one of the largest constellations of satellites

- 3U CubeSats (10x10x30 cm)

- 110+ satellites launched

- 30+ globally distributed ground stations

- Focus on signals of opportunity using software defined radio payloads
    - GNSS
        - 42 sats RO-capable and 26 in RO production
        - 4 GNSS-R sats
    - AIS (ship tracking)
    - ADS-B (aircraft tracking)

- Hosted payloads / Orbital Services


spire
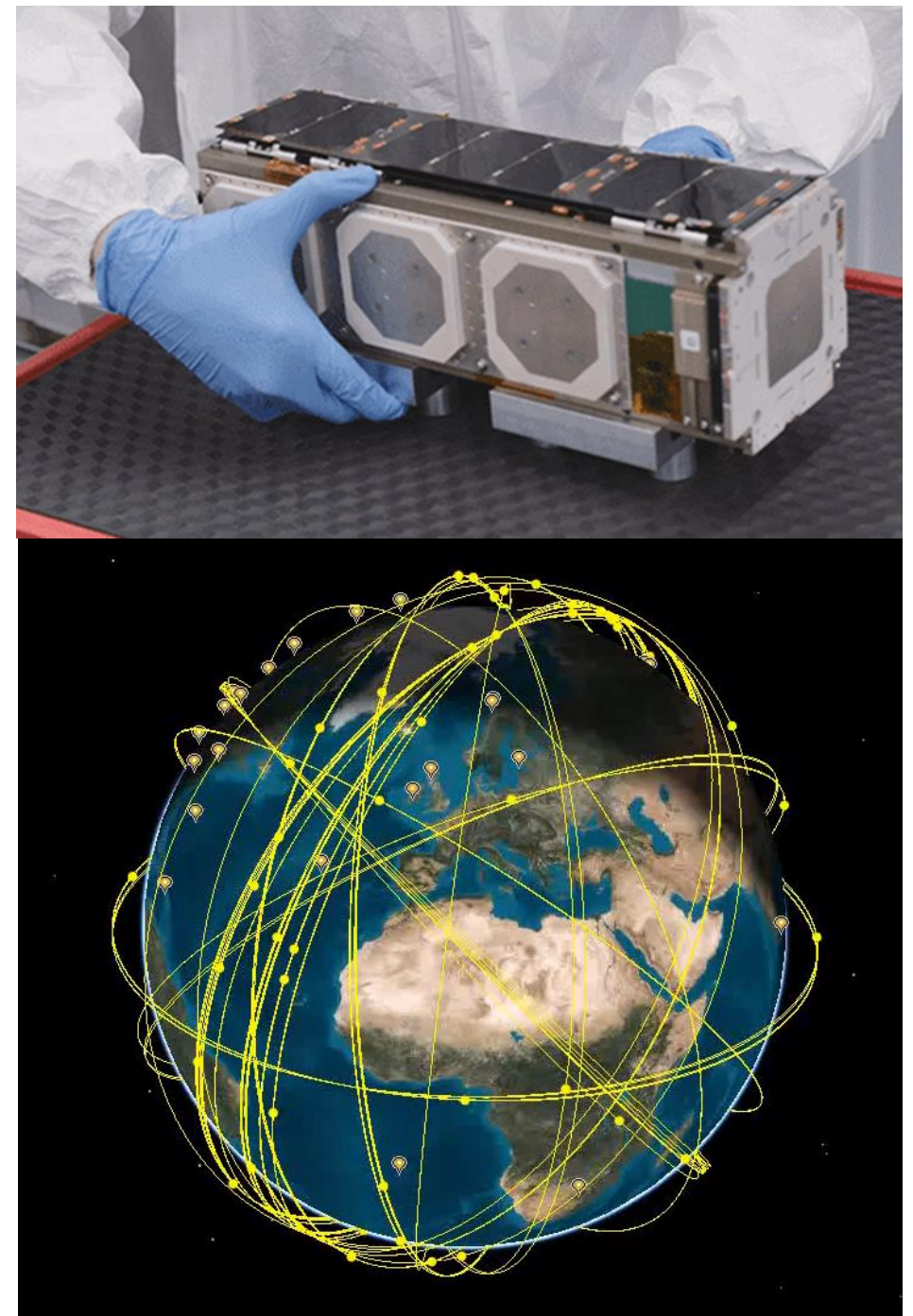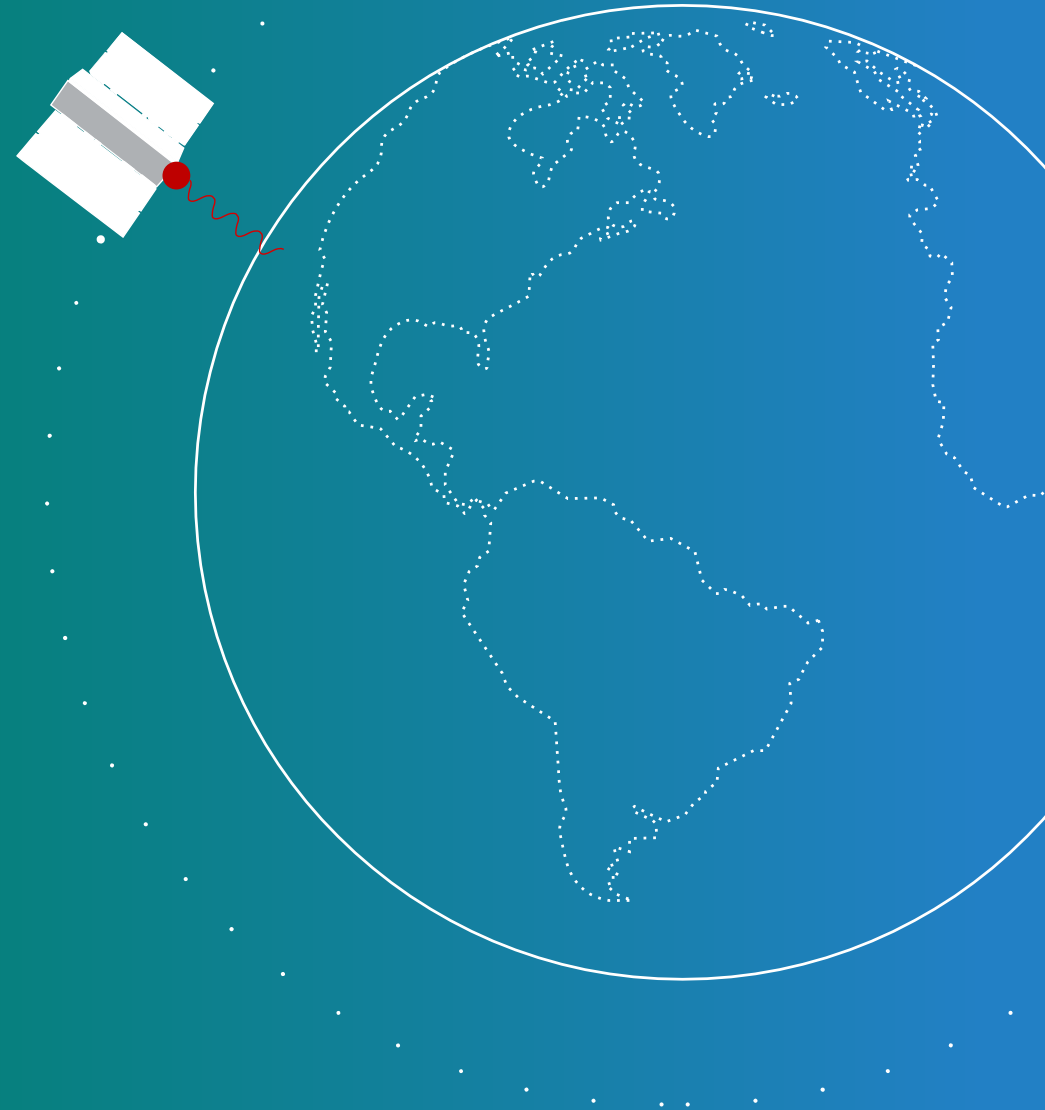
SpWx data

SpWx data
Instrument

- STRATOS GNSS Receiver for remote sensing and precise orbit determination
  - Software-defined
  - Dual-frequency
  - Approx. 200 g, 4 W
- Performs POD using zenith antenna
- Performs radio occultation (RO) on high-gain, forward (rising) and backward (setting) antennas
- GPS, GLONASS, Galileo, and QZSS processed
- Is being superseded by STRATOS-2
  - Wide-band, direct sampling receiver
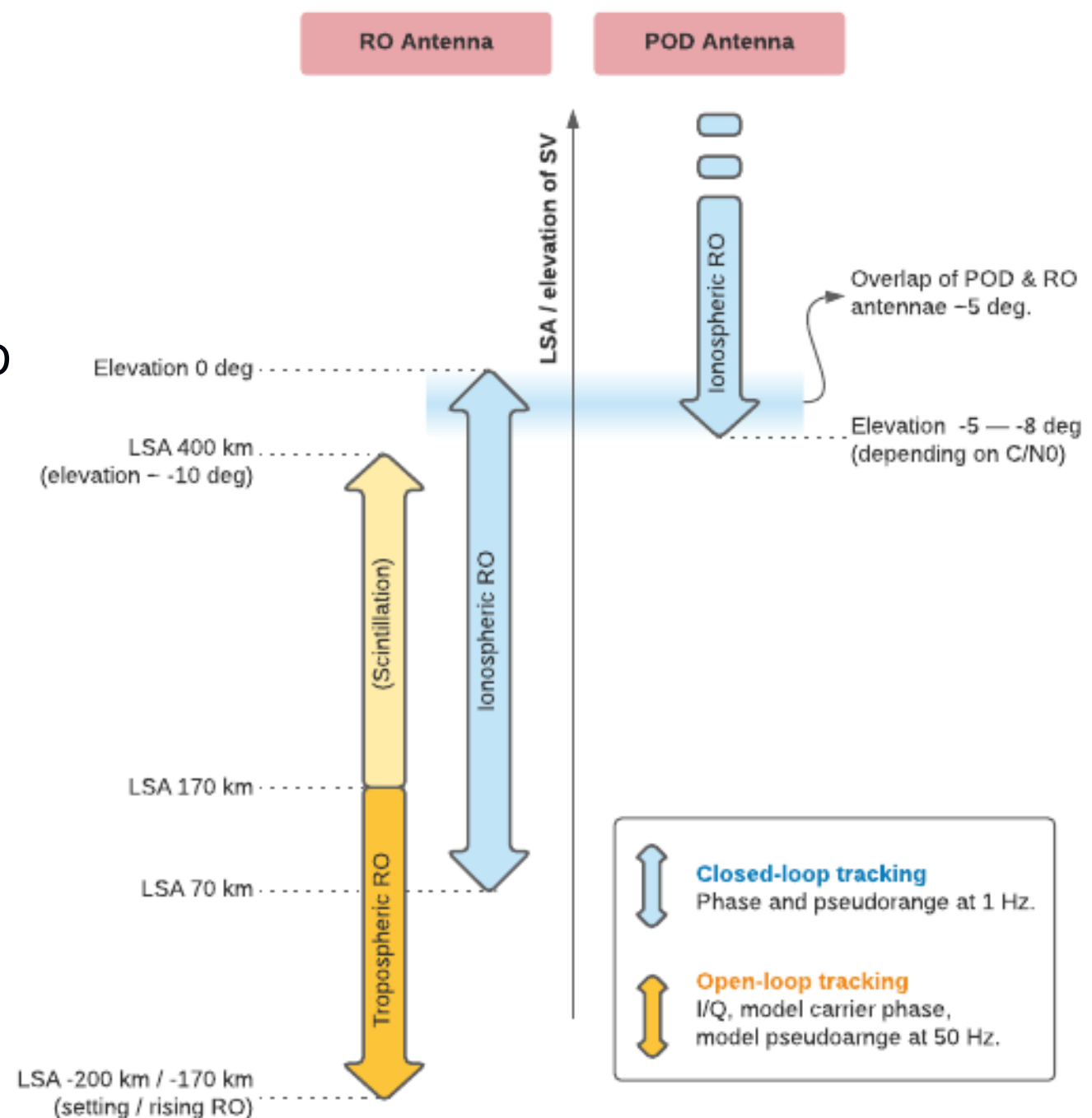 - Internal phase calibration system for differential code bias estimation
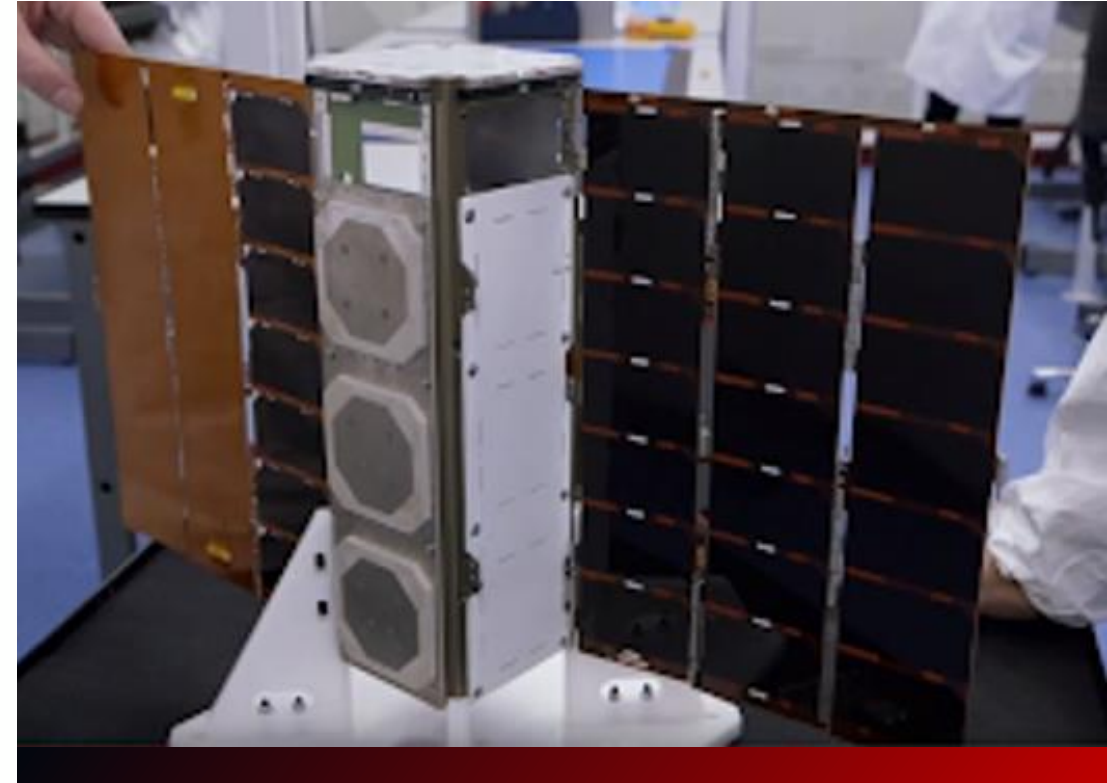
GNSS Earth observations
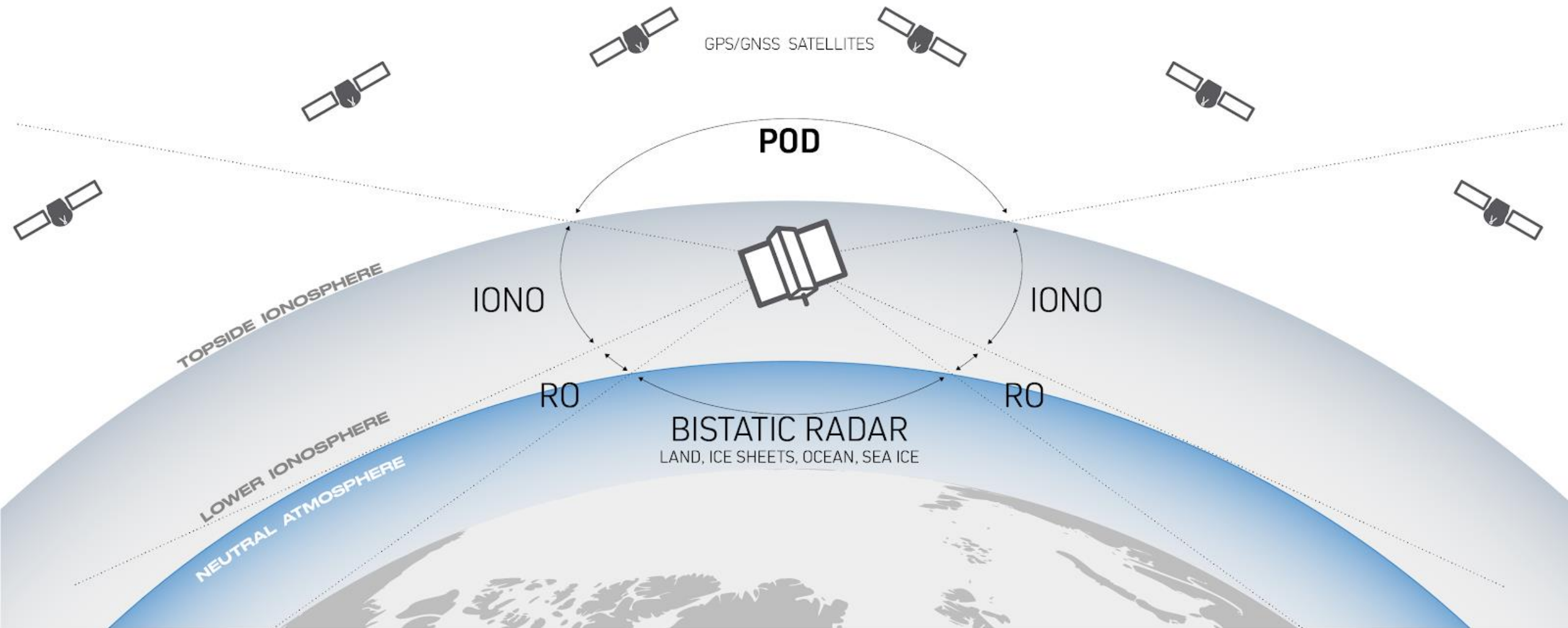
SpWx data
Collection strategy

- SpWx relevant data collected from both POD and RO antennas

- POD antenna
  - 1 Hz, closed loop tracking

- RO antenna
  - 1 Hz, closed loop tracking
  - 50 Hz open loop tracking
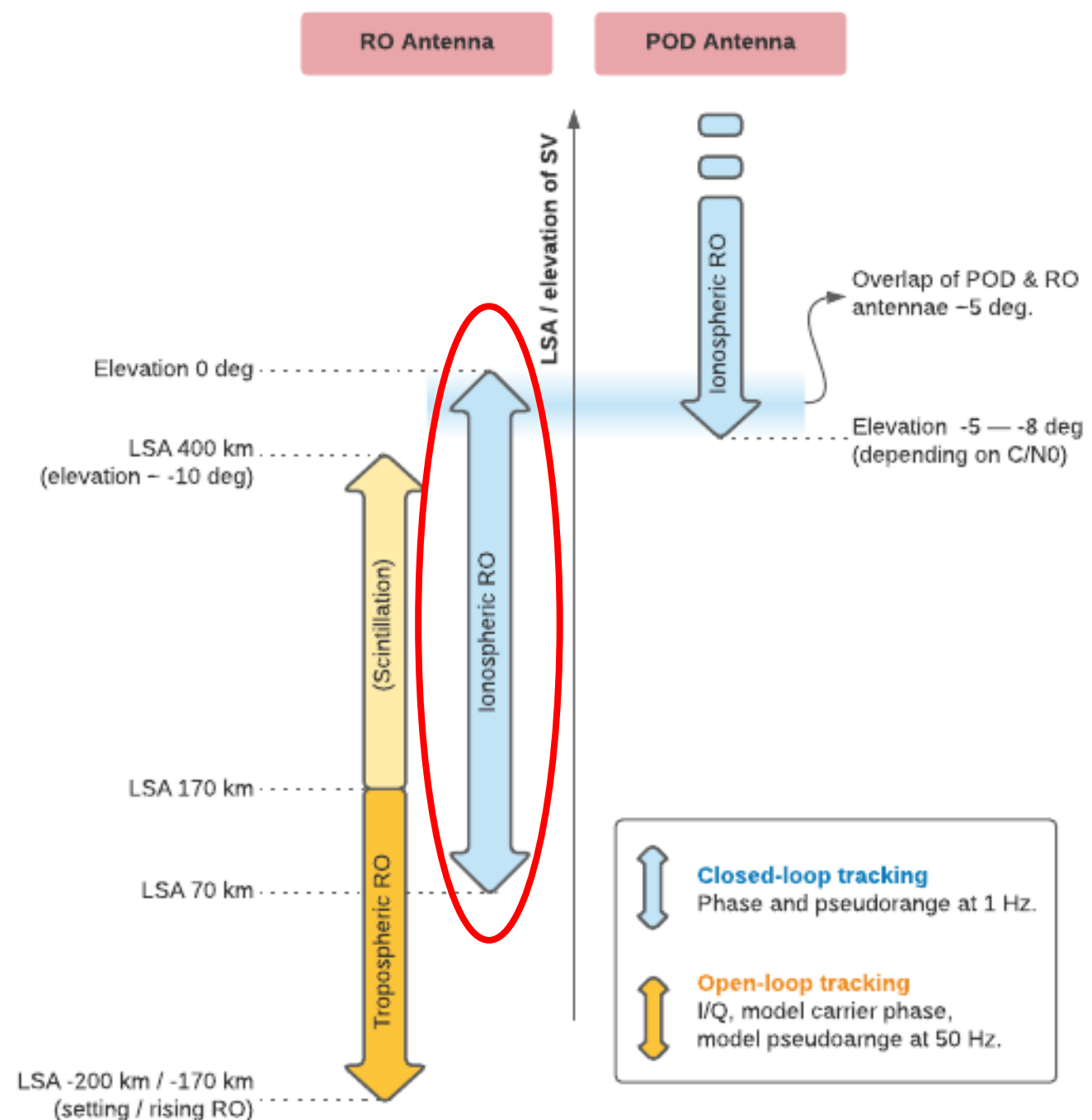
SpWx data
POD antenna

- Topside ionosphere and plasmasphere
  - Calibrated TEC

- 1 Hz, closed loop tracking

- GPS only

- TEC estimated from phase and pseudorange

- Weekly DCB estimate

- Approx. 9 Msamples/day
  - c.f. 5 Msamples/day in April 2019

2021-03-01 TP of TEC ray
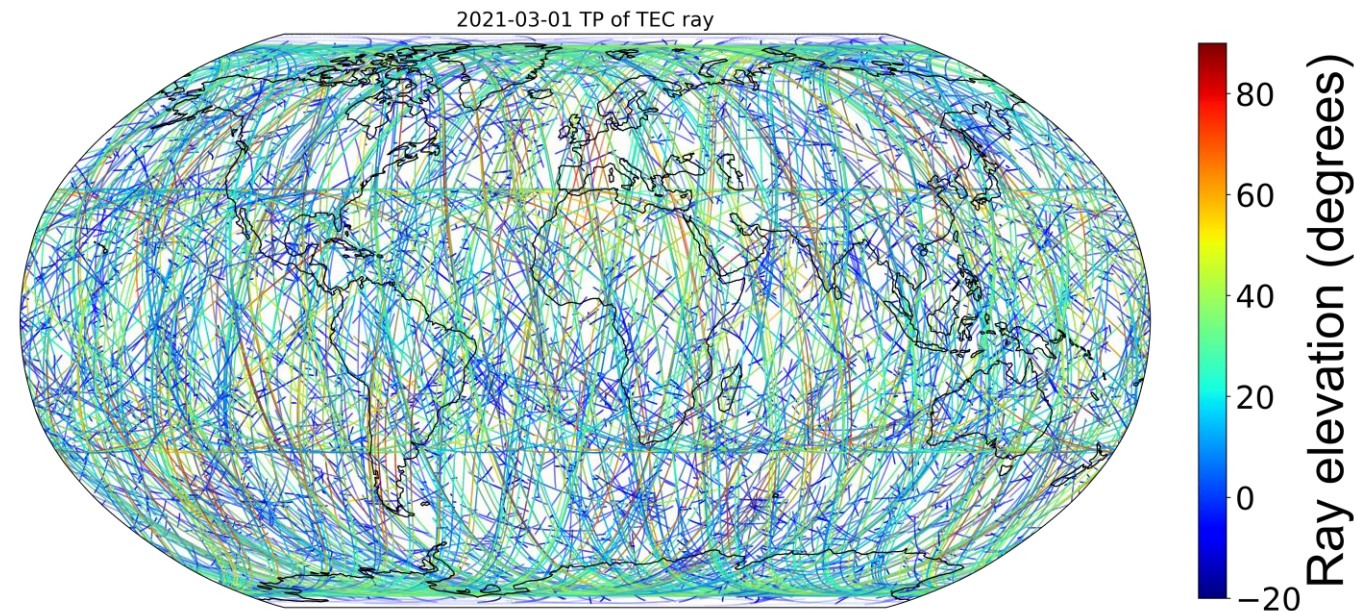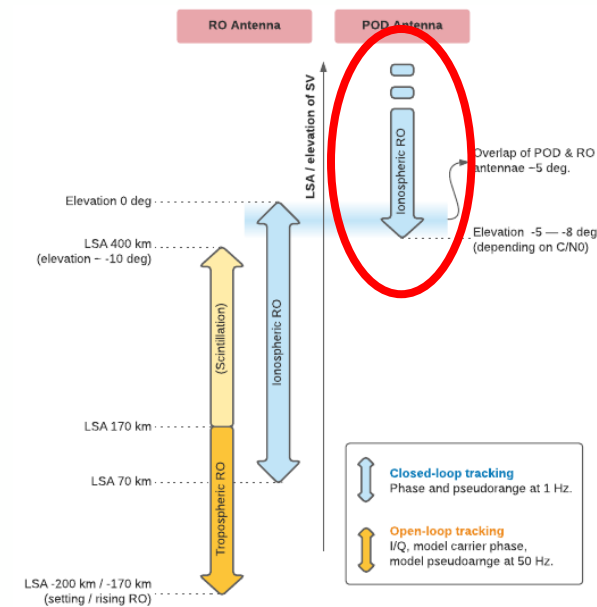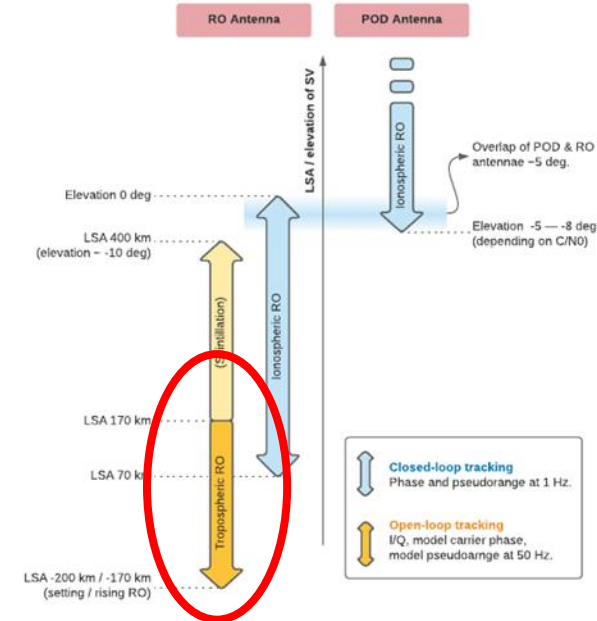
SpWx data
RO antenna

- Bottomside ionosphere
  - Relative TEC
- 1 Hz, closed loop tracking
- GPS only
- TEC estimated from phase and pseudorange
- Approx. 4000 events per day
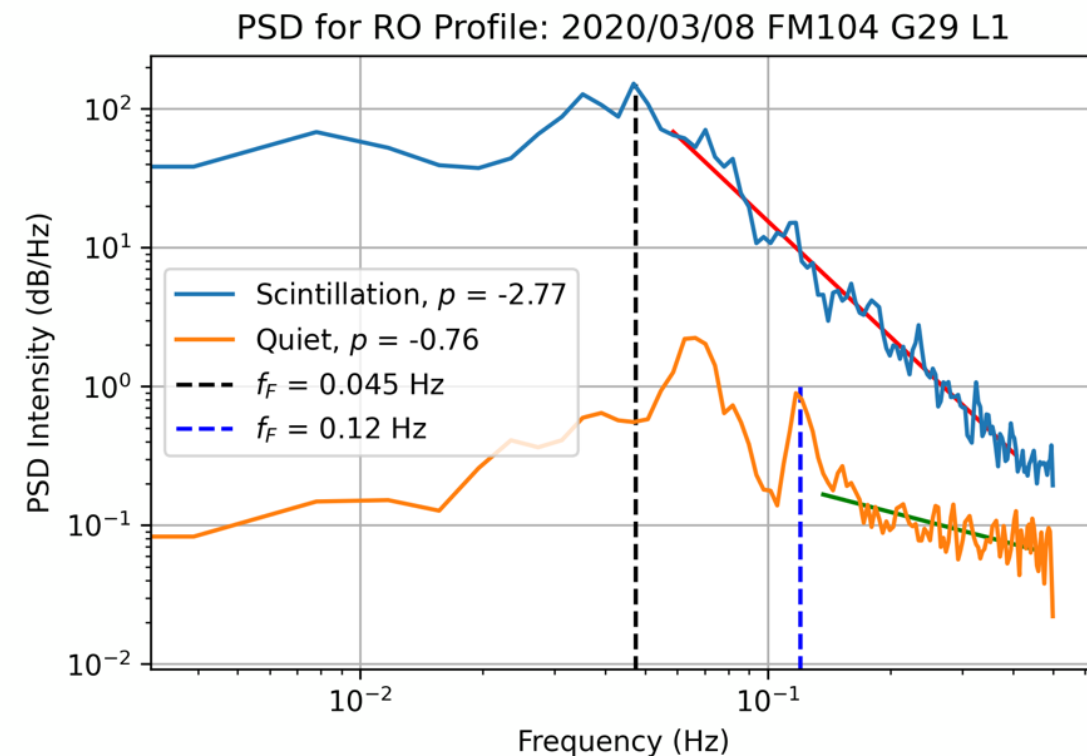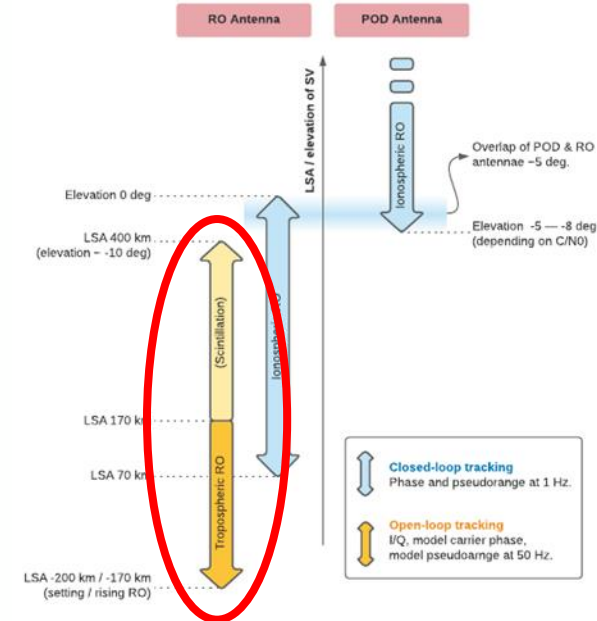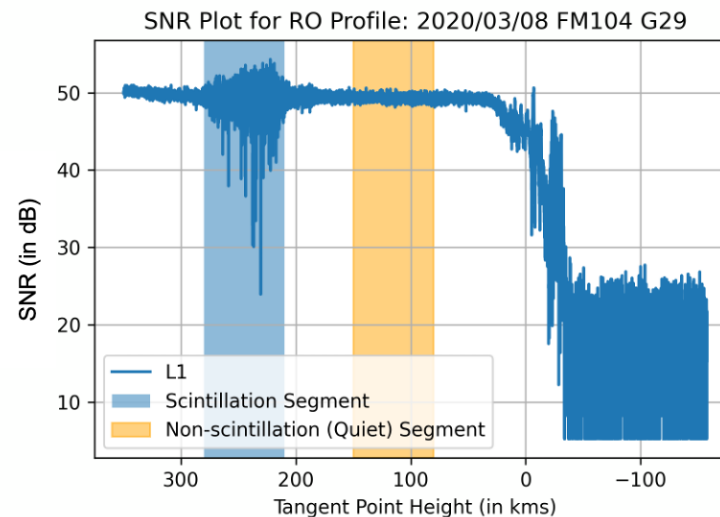
SpWx data
RO antenna

- E region ionosphere
  - Relative TEC
  - Perturbation detection and classification

- 50 Hz, open loop tracking

- Multi-constellation

- "Bottom-up" relative TEC from phase

- Machine learning methods used to group similar profiles

- Approx. 9000 events per day
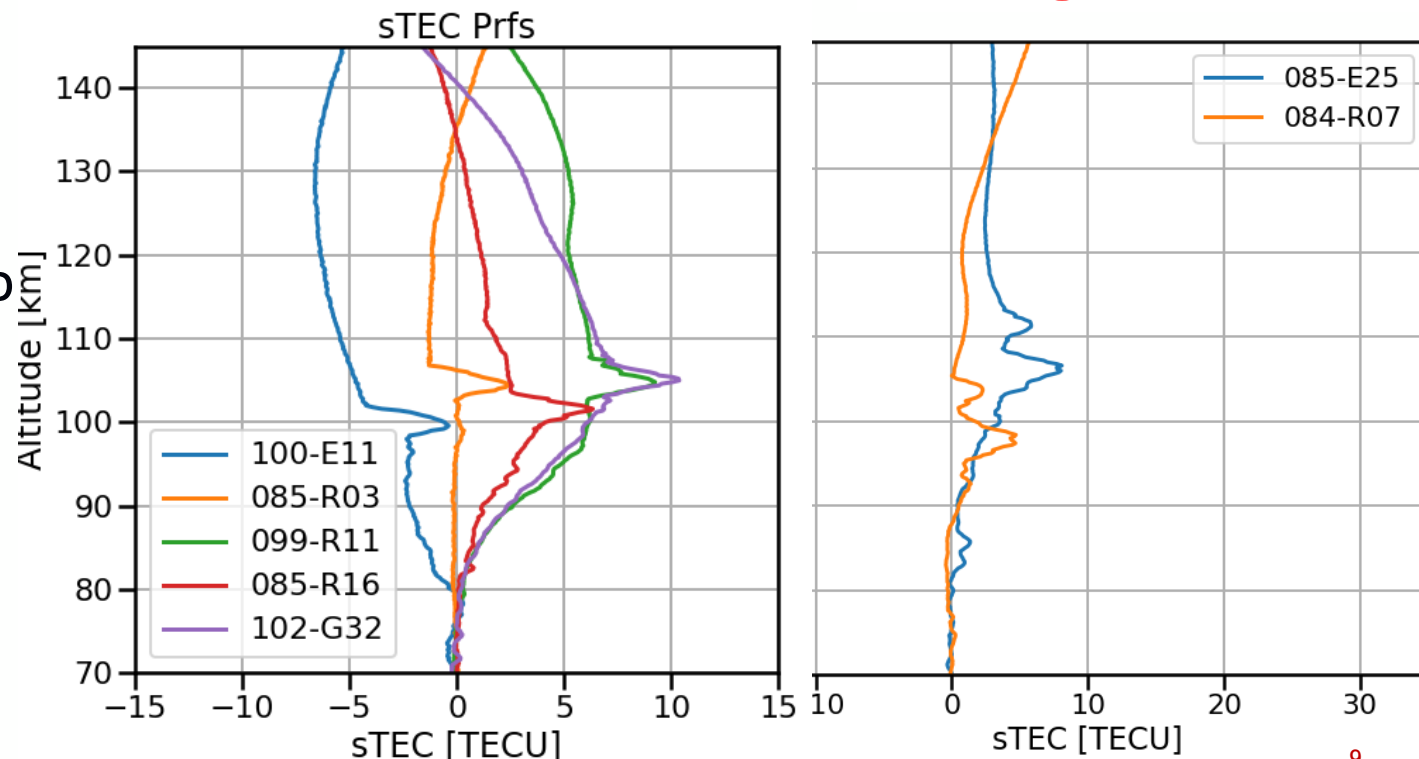
SpWx data
RO antenna

- Ionospheric scintillation
  - Scintillation indices

- 50 Hz, open loop tracking

- Multi-constellation

- On-board estimation of S4

- Retain and downlink high altitude 50Hz data if S4 exceeds threshold

SNR Plot for RO Profile: 2020/03/08 FM104 G29

PSD for RO Profile: 2020/03/08 FM104 G29 L1

SpWx data
Future

- Combined ionosphere product
- Level RO antenna TEC data to POD antenna TEC data
  - Calibrated data across extended height range
  - Estimate of POD antenna DCB
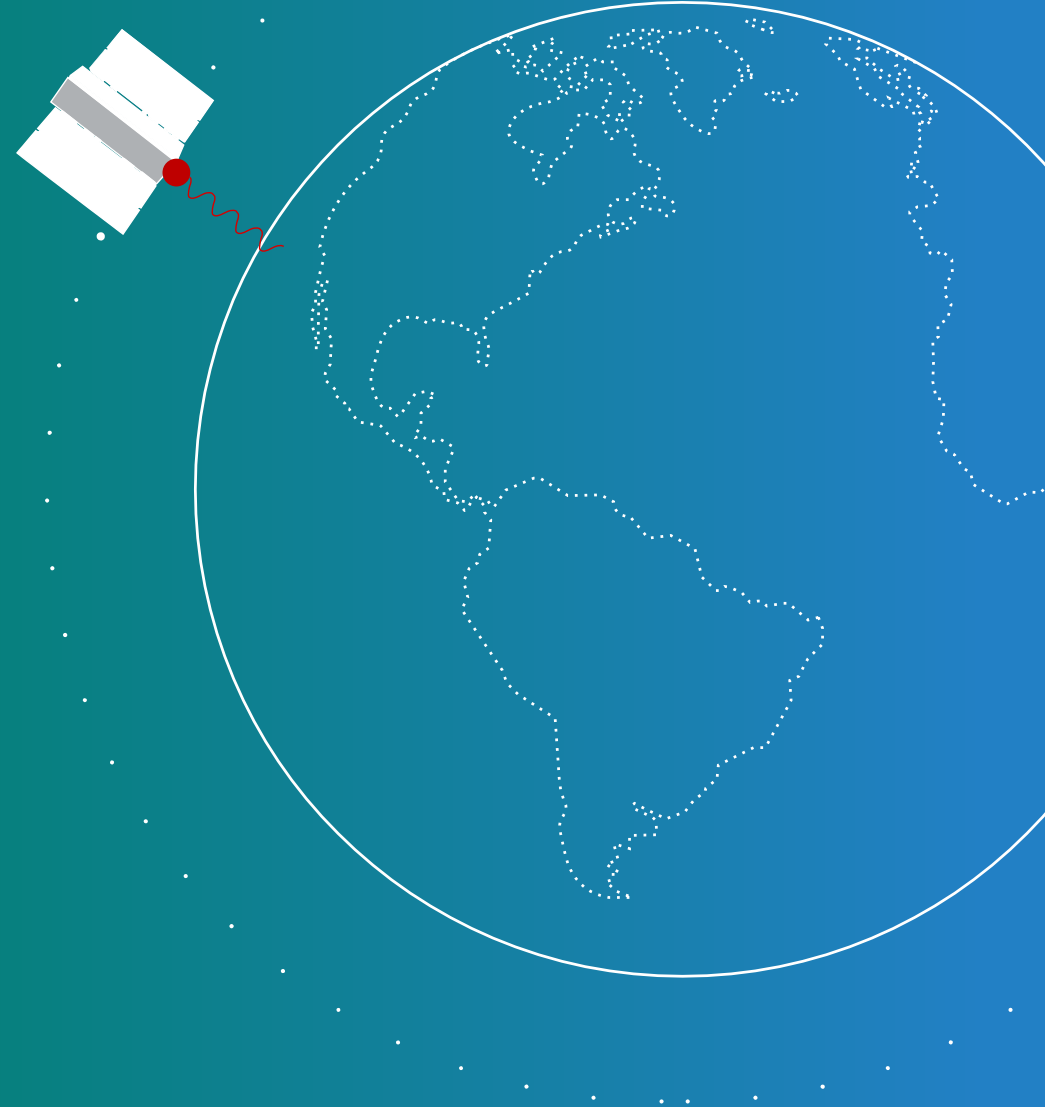- To be rolled out in 2021
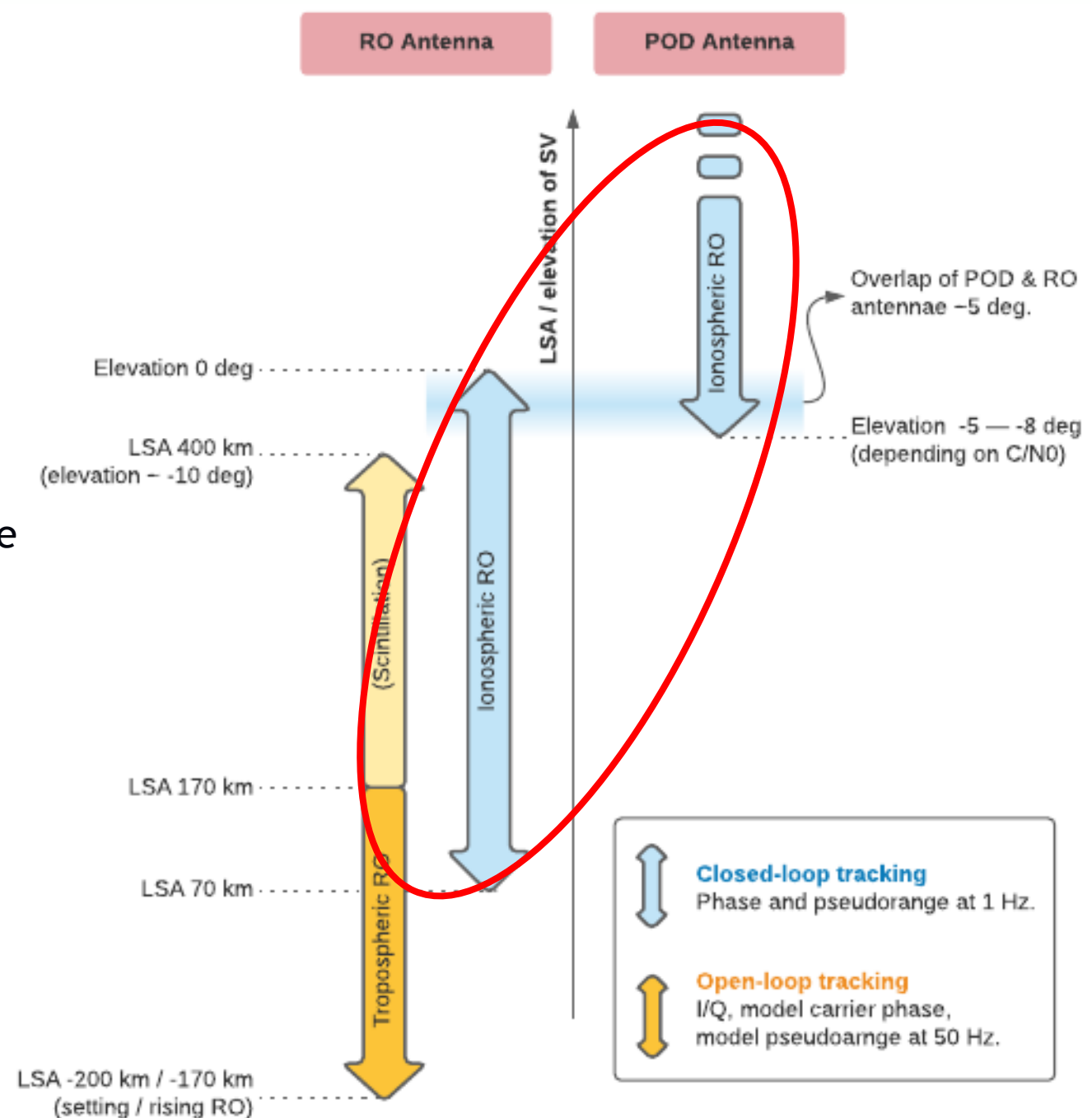
SpWx data
Future

- Thermosphere
  - Density estimates
- POD data can be inverted to estimate thermospheric drag
- Combined with better drag coefficient models to provide density estimates
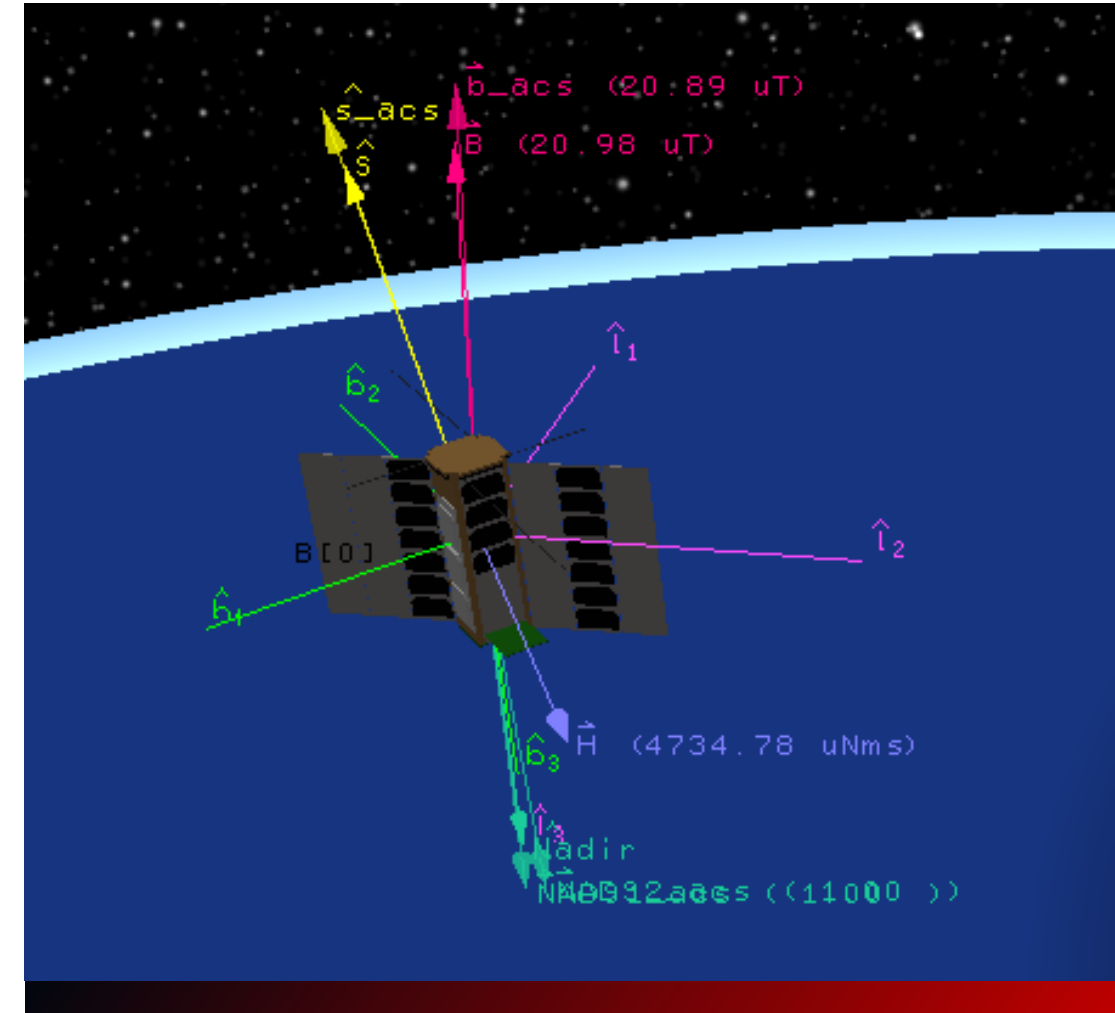
SpWx products

Ionospheric DA

- Spire TEC data is suitable for use in data assimilation models
- DA is required to:
  - Overcome the limitations of the traditional Abel Transform analysis of RO data
  - Effectively combine different types of observation
- Spire TEC Environment Assimilation Model (STEAM)
  - 4D Local Ensemble Transform Kalman Filter
  - Routinely uses ground and Spire data
 - Experimental Spire/COSMIC2 DA
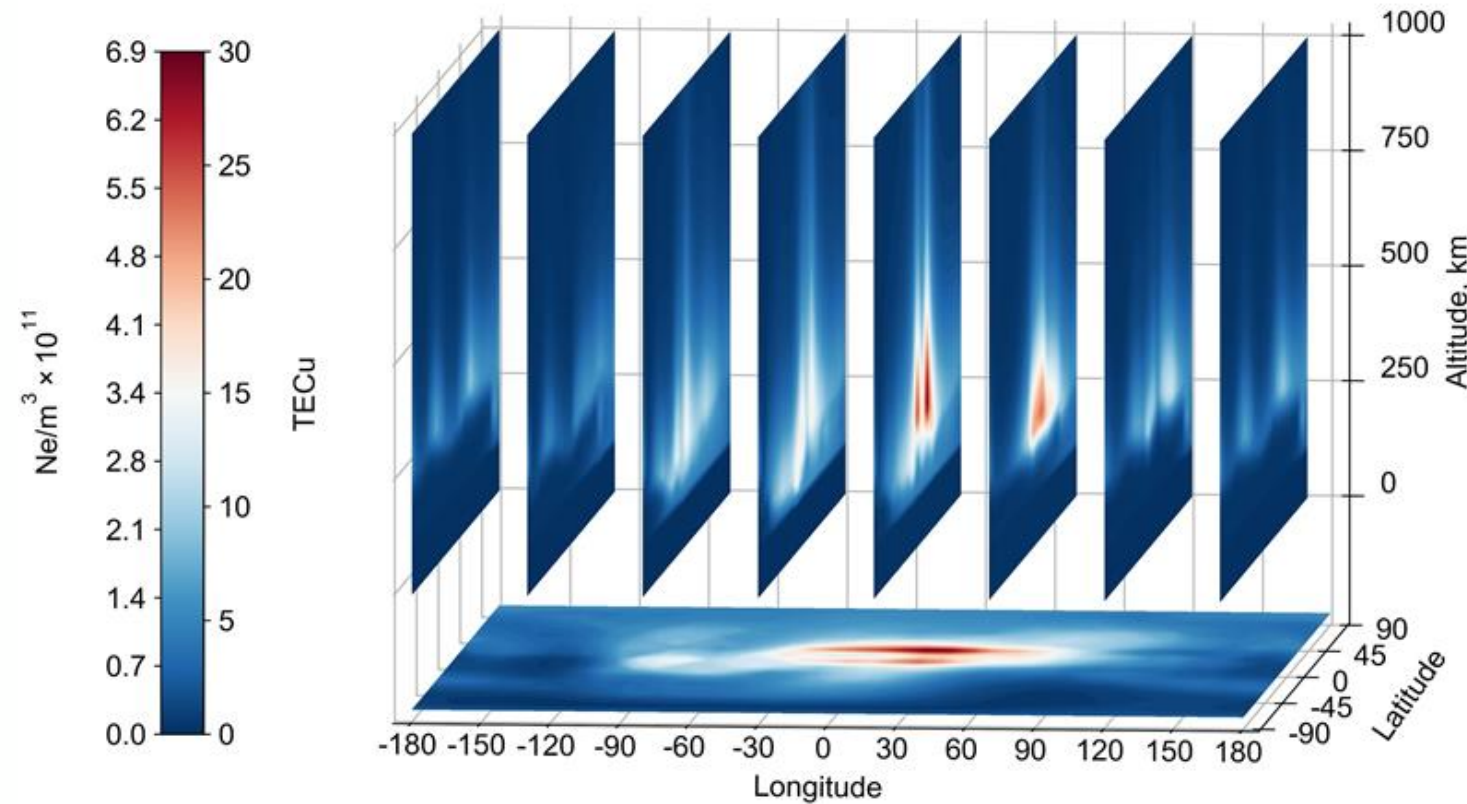
ICAO products

- ICAO has a requirement to provide space weather advisories to aviation users

- STEAM ensemble can be used to estimate probability of VTEC falling in bands
  - The probabilities can be mapped to RGB colours
  - Red region: high confidence vTEC is within severe band
  - Blue region: high confidence vTEC is within moderate band
  - Green region: high confidence vTEC is within quiet band

2021/01/06 08:30:00 UTC
Created on 2021/01/06 10:03 UTC from STEAM v5.2

Quiet
0-10 TECU

Moderate
10-20 TECU

Severe
> 20 TECU

ICAO Probability Values during Flight
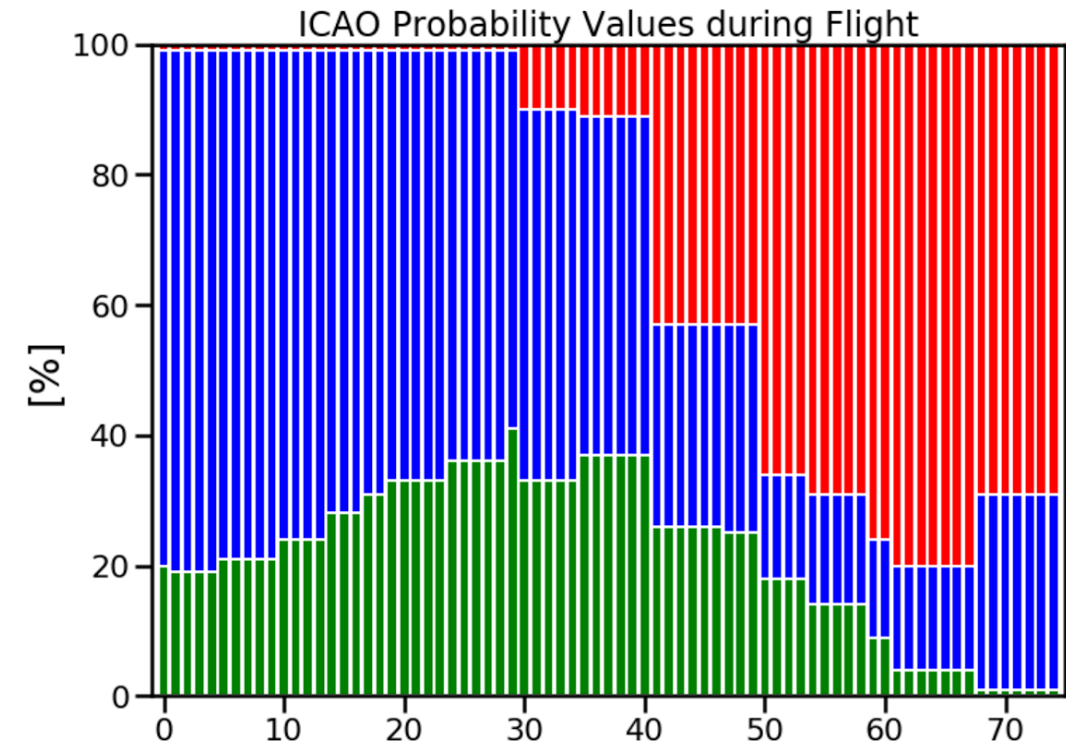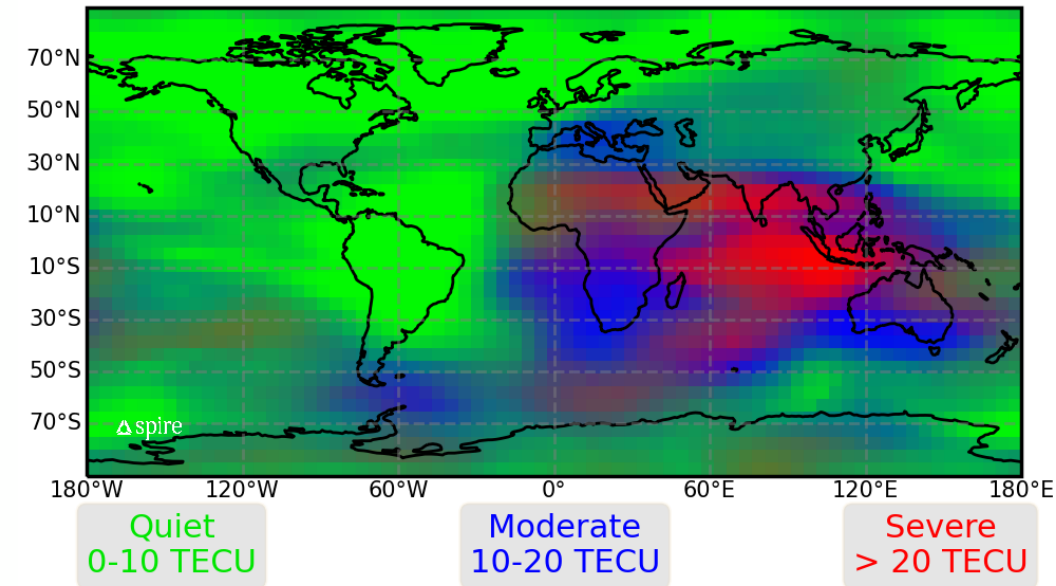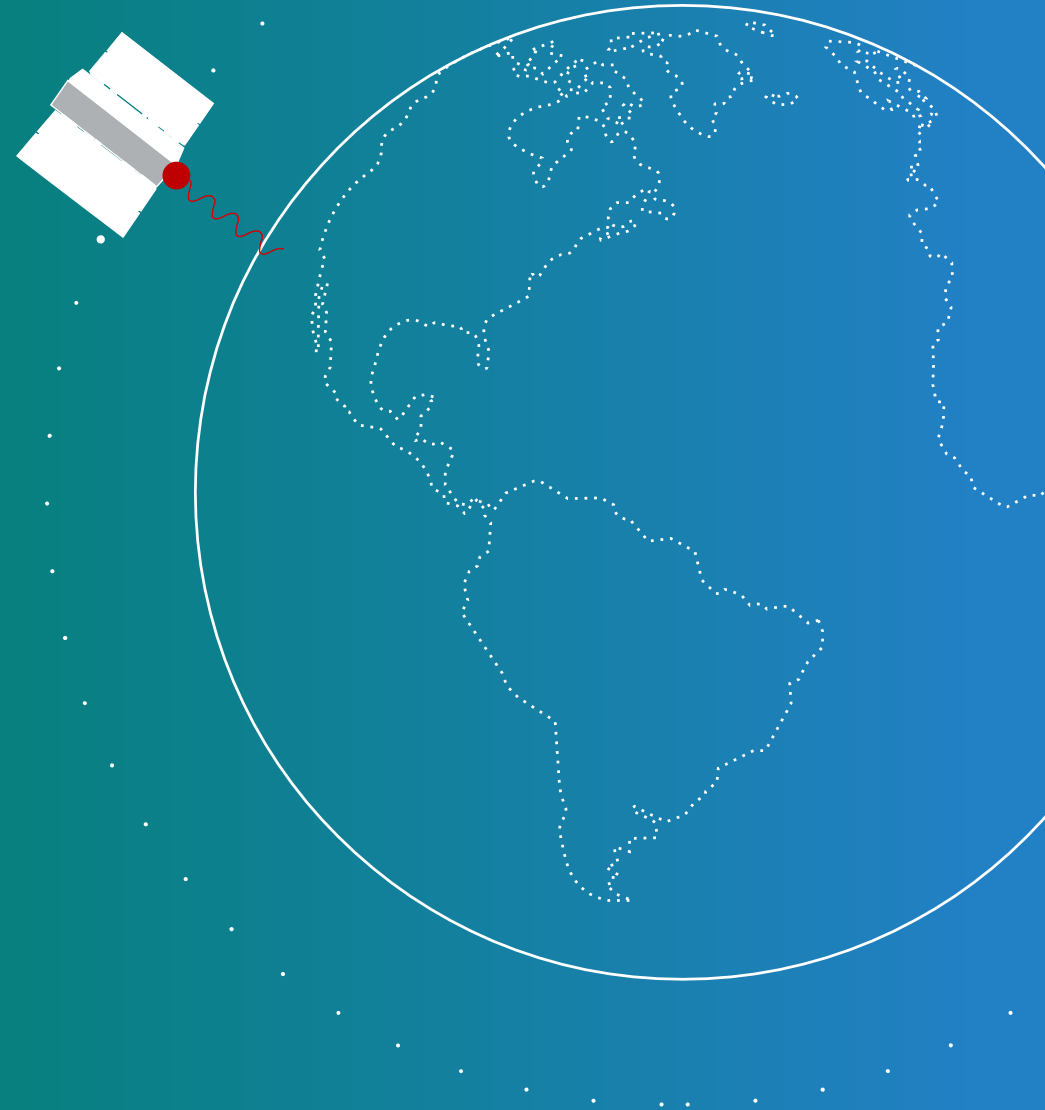
Conclusions

Conclusions

- Ionospheric information can be derived from GNSS signals

- Ionospheric sensing on different scales
  - Global
    - Slant total electron content (TEC)
  - Mid-scale
    - Sporadic E, travelling ionospheric disturbances
  - Small scale
    - Scintillation events

- Thermospheric sensing being developed

- Spire provides these observations
  - In data denied areas
  - With low-latency
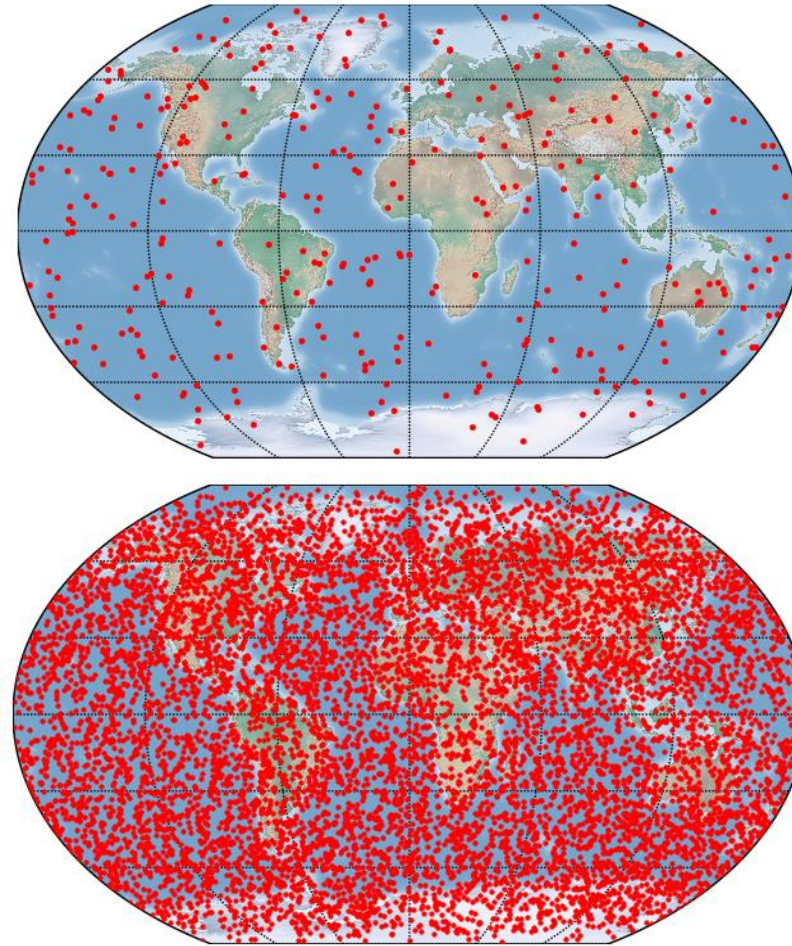
June 2018: 100s RO profiles/day
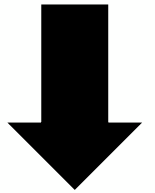
Feb. 2020: ~10K RO profiles/day (100x increase)